

Appendix C

Geologic Mapping of Tunnels and Shafts

C-1. Background

A method to log all geologic features exposed by underground excavations has been developed by U.S. Army Engineer District, Omaha, geologists wherein all necessary data of a specific geologic discontinuity can be recorded at a single point; thus the system may be used in tunnels of almost any configuration and inclination. This method is called peripheral geologic mapping. It allows logging of all geologic defects regardless of their position on the tunnel walls. Furthermore, this method usually will keep pace with modern continuous mining techniques and will immediately provide useful data without projecting to plan or profile. Prior to development of this method, the accepted method was to project geologic features to a plan placed tangent to a point on the tunnel circumference. Ordinarily such tangent points were at springline, wasteline level, or crown. In many instances, geologic features not passing through these points were not logged. Further, some systems were useful for logging planar discontinuities only, such as joints, faults, and bedding planes, as exposed in straight, nearly horizontal tunnels of circular cross section. Peripheral geologic mapping uses a developed plan by “unrolling the circumference” to form a plan of the entire wall surface. A log of the exposed geology is plotted on this plan as mining progresses. Mapping on a developed layout of a cylindrical surface is similar to the method used to log the interior of a calyx hole. Actually, a circular tunnel might be visualized as a large horizontal or nearly horizontal drill hole.

C-2. Applications

Peripheral geologic mapping may be used to log large-diameter power tunnels and surge tank risers (both straight and wye-shaped), vertical shafts, horseshoe-shaped drifts and chambers, and odd-shaped openings on both civil and military projects. It can be used to map a wide range of geomaterials from stratified, soft, sedimentary rocks to hard igneous and metamorphic rock masses. The method has proved to be simple enough mechanically that technicians can be trained to perform round-the-clock mapping under the general supervision of a professional geologist - a necessity where several parallel tunnels are driven simultaneously. This method is not applicable to TBM driven tunnels with precast liners where mapping may be impracticable or impossible.

C-3. Procedure

a. Advance planning is of paramount importance. The developed layouts on which mapping will be done should be prepared well in advance. Usually this step in the procedure can be accomplished by using the contract plans. A thorough surface and subsurface study of the geology of the immediate area is recommended. This study enables the mapper to recognize which geologic features are important and readily identify them on the excavation walls.

b. The map is typically laid out to a scale of 1 cm = 1.2 m (1 in. = 10 ft). In some instances where closely spaced geologic discontinuities are anticipated, a scale of 1 cm = 0.6 m (1 in. = 5 ft) should be considered. To prepare a mapping plan, draw the crown center line of the tunnel in the center of the plan. Place the center line of the invert at both the right- and left-hand edges of the developed layout. The right and left springlines of a circular tunnel will be midway between the center line and edges of the plans (Figure C-1). Distances down the tunnel may be laid out on tunnel stationing. Separate developed plan tracings are typically made for 100-ft lengths of tunnel. For long reaches of equal-diameter tunnel, a master tracing may be repeatedly printed on a continuous length of paper to cover the entire tunnel

length. For continuous uninterrupted printing, use three master tracings. This long sheet of paper may be rolled up and carried in the field in the form of a scroll.

c. Intermediate control points should be added wherever possible to more precisely locate points along geologic discontinuities. On Figure C-2, which is a mapping sheet used at Fort Randall Dam, South Dakota, the horizontal distances from the center line and vertical distances from springline were computed and drawn on the developed plan to form a grid. When plotting a point, the mapper measures these two distances (horizontal distance from center line and vertical distance above or below springline) and plots the point at the proper tunnel stationing. To eliminate long measurements in large-diameter tunnels, distances were actually measured from fixed known points on the tunnel support ring beams (splices, bolt holes, and spreader bars). At Oahe Dam, South Dakota, horizontal and vertical distances of fixed features on the ring beam supports were drawn on the mapping sheets as lines so that points on geologic features could be plotted from the nearest ring beam reference point. On Figure C-3, which is a mapped portion of Oahe Dam power tunnel No. 2, a developed ring beam is shown at the top of the page, vertical distances from springline of identifiable fixed points on the ring beam are shown along the top of the mapping section, and horizontal distances from center line of these same points are shown along the bottom of the mapping section. The ring beam number and its tunnel station is shown along the right-hand edge. Excellent mapping control was thus provided on this project. In excavations not requiring close checks on alinement, control points may be almost nonexistent. In such cases, the mapper must establish his own control points. He may have to stretch a tape along the tunnel from the nearest spad, then mark stationing at 1.5- or 3-m (5- or 10-ft) intervals along the walls and use an assumed elevation at his reference point. Obviously, the resultant geologic log will not be as accurate, but the relative position of discontinuities should remain constant from tunnel wall to geologic log.

d. The conventional method of measuring the strike, or orientation of a joint, shear, or fault, by magnetic needle (Brunton) compass is not reliable in most underground work because of the proximity to electrical circuits, reinforcing steel, or support steel. Also in some areas, the rock mass itself may be magnetic. To overcome this problem, an adjustable protractor can be devised. Essentially, it is an instrument for measuring the angle between the trend of a planar geologic defect, as measured in the horizontal plane, and the bearing of the tunnel center line. The protractor is fitted with a revolving pointer, which rotates around the center point of the protractor. The baseline of the protractor is held parallel to the tunnel center line, the pointer is sighted along the strike of the discontinuity, and the angle is read on the protractor at the point where a line scribed on the pointer coincides with the degree lines on the protractor arc (Figure C-4). The strike of the geologic defect is then computed from the observed angle and the bearing of the tunnel. In small-diameter drifts, tunnels, adits, etc., a small, light, fixed-base protractor will be adequate for fairly accurate readings. In large-diameter openings, a special protractor may be constructed that has an adjustable baseline. The baseline of the instrument is then revolved to the known tunnel bearing so that direct readings of strike may be taken (Figure C-4). A circular spirit-level bubble may be mounted on the instrument to assure that readings are in the horizontal plane. Dip readings are observed by using the inclinometer on a Brunton compass or pocket transit.

C-4. Helpful Suggestions

a. The geologic features that have the greatest effect on the physical and engineering properties of the rock mass should be logged first. A classification for rock masses for tunnel support are described in EM 1110-2-1901. Geologic logging should be performed near the heading as fresh rock is exposed, before the exposed walls become dust covered or smeared over, and before the geologic features are partially or completely covered by tunnel supports, lagging, pneumatically placed mortar, etc. The mapper should ensure that adequate lighting is available. Mapping should be from the back of the mining machine or on the drill jumbo to help the mapper reach the higher sidewalls and crown in

large-diameter tunnels. The main geologic features, such as faults, joints, shear zones, bedding planes, and clay seams, should be carefully plotted first. Then as time permits, other less important features may be filled in between the previously plotted features on the geologic log. Additional features to be logged include fractures, stressed zones, fallouts, water seeps, etc. These features make up only a partial list because additional important geologic features will be encountered at each specific project.

b. In large- and medium-diameter tunnels, consecutive mapping sections may be printed on a long sheet of paper to form a scroll. This continuous length of paper can be carried on a mapping board so designed that only the section being mapped is exposed while the remainder of the roll is enclosed in boxes on each side of the mapping board. Cranks and rollers may be added to assist in moving the proper section onto the mapping board. The board may be faced with a piece of sheet metal to provide a smooth writing surface. In small or odd-shaped tunnels or drifts, the mapping sheets are usually carried in individual, conveniently sized sections. A covered clipboard makes a good mapping board. The cover is to protect the mapping sheets from the ever present dust, moisture, etc., associated with underground excavations.

If necessary, the mapper can extend his own control from known points. A steel tape is stretched along the tunnel and 1.5- or 3-m (5- or 10-ft) station intervals may be marked on the wall or supports with spray paint. Photographs of important or unusual geologic features are a valuable addition to the mapping. It is also suggested that a small portable tape recorder for noting the location and attitude of secondary features will help the mapper, especially in adding secondary features to the mapping when time in the tunnels is limited.

c. The completed geologic log of a horizontal or nearly horizontal tunnel will wrap around a mold of proper dimensions to form a model with the mapped features and recorded information in their proper position; however, the geologic log of peripheral mapping in a vertical shaft or end face will not be in its proper position unless the information is traced through the paper to reverse the image. The reversal of the image presents no particular problem because in most instances the field maps and data are transcribed to finished drawings in the office. The geologic section in Figure C-5 was not reversed; therefore the observer appears to be in the shaft looking outward. Also in odd-shaped raises or in vertical shafts, it is difficult for the mapper to remain properly oriented unless vertical reference points around the periphery have been surveyed-in prior to the start of geologic mapping.

C-5. Analysis of Data

a. Although peripheral geologic logging, or mapping, provides a permanent record of all geologic defects exposed on the walls of an underground excavation, maximum benefits cannot be gained unless the data are properly studied and analyzed. One study method is cutting and trimming the drawings and forming them into the proper shape for three-dimensional viewing, which causes the relationship of discontinuities to the tunnel geometry to become much more apparent.

b. Projection of the trace of geologic discontinuities to two-dimensional plans or profiles may be made, but not directly, because the mapping has been done on a developed plan. One method of transferring data to plan is by plotting to corresponding stationing. Data may be transferred to profile, or cross section, by plotting the points where the discontinuities intersect measured stationing at crown, invert, and/or springline. Where only one point can be plotted, the trace of the discontinuity may be extended along a line drawn on the recorded strike or dip of a discontinuity (the use of apparent dip may also be necessary). Figure C-6 illustrates a method of projecting geologic data to sections drawn through a circular tunnel.

c. Statistical studies may be made from the accumulated data. By counting all discontinuities per unit of length and circumference, an average piece size or block size may be determined. Plotting the trends of joints, faults, and shears on equal-area nets and stereographic projections (Hobbs, Means, and Williams 1976)¹ will help determine the major and minor joint sets and the preferred orientation of faults and shear zones. Another method of statistical analysis might be by making rosette plots of the joints and shears.

C-6. Uses for Geologic Data

The value of peripheral geologic mapping has been proven many times. Below are listed some of the uses for this type of geological logging.

- a.* Predicting geologic conditions in intermediate tunnels where driving a series of parallel tunnels .
- b.* Projecting geology from the pilot drift to the full bore of a tunnel before enlarging is started.
- c.* Planning tunnel support systems and selecting the best location and inclination of supplemental rock bolts.
- d.* Maintaining a record of difficult mining areas, overbreak and fallout, and mining progress by daily notation of the heading station. This type of record is valuable in changed condition claims.
- e.* Comparing cracking of concrete tunnel liners with weaknesses logged in tunnel walls.
- f.* Analyzing stress conditions around tunnel openings using methods that evaluate the spacing and orientation of geologic discontinuities.
- g.* Choosing strategic locations for various types of instrumentation to study tunnel behavior.
- h.* Selecting the best locations for pore pressure-type piezometer tubes where it is desirable to position them to intercept particular types of discontinuities at specific elevations near previously driven tunnels.

Proctor and White (1977) and Dearman (1991) also provide useful information regarding the geotechnical aspects of rock tunneling.

C-7. Examples

a. The preceding description of peripheral geologic mapping was based primarily on logging, which was done in circular, nearly horizontal tunnels and vertical circular shafts. With some modifications and a degree of ingenuity, the method can be adapted to almost any shape of underground opening. For some projects, the preplanned developed layouts may have to be made by using patterns taken from heating and cooling ductwork manuals.

b. Figures C-7 through C-9 are offered for general guidance only. The method may be modified to fit anticipated conditions peculiar to a specific project. For example, in Figure C-8 only the curved

¹ References are listed in Appendix A.

portion above springline was laid out on a developed plan and the vertical sidewalls below springline were laid out on true scale. No provisions were made for mapping the drift floor because it was not cleaned sufficiently to expose the geological features.

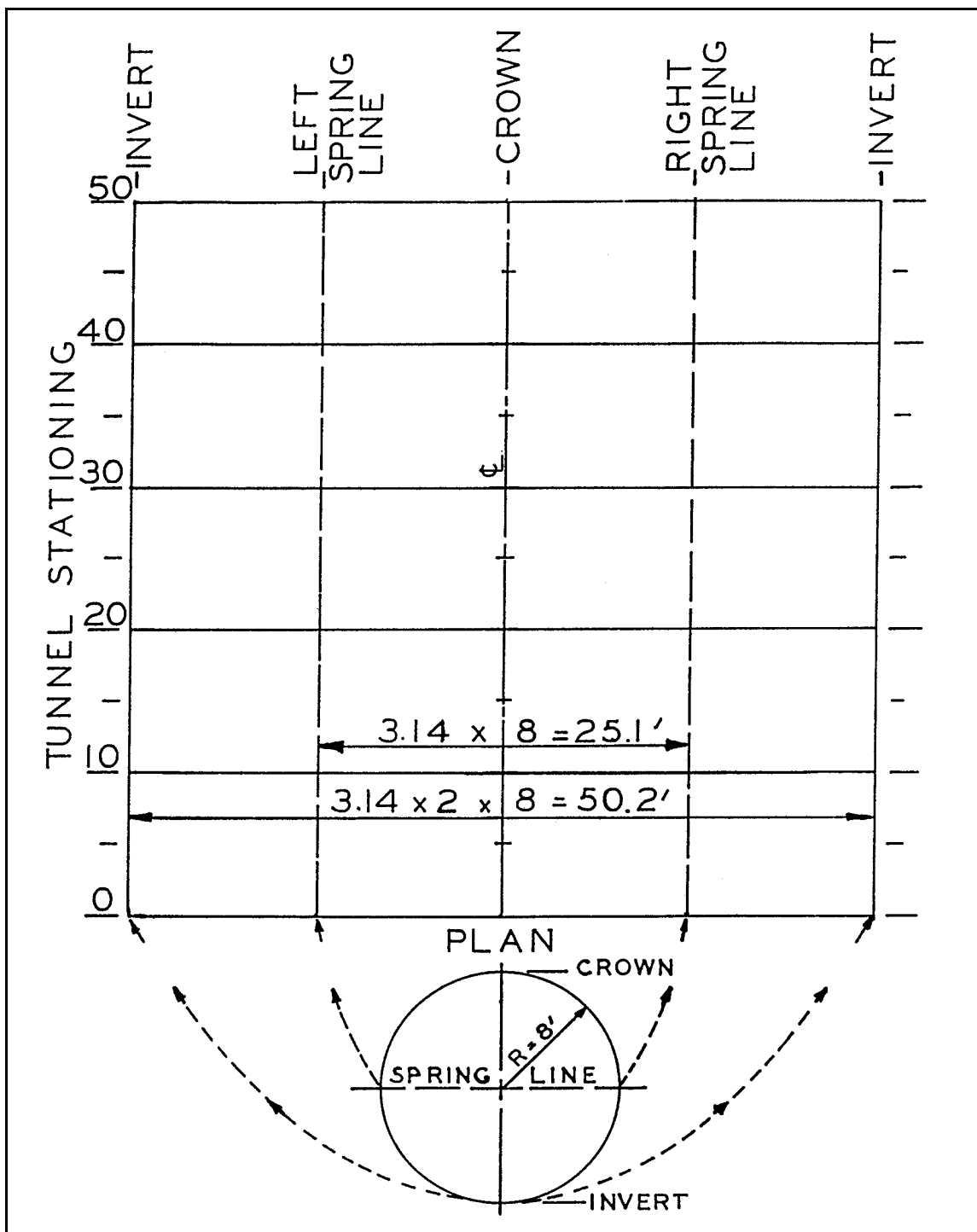
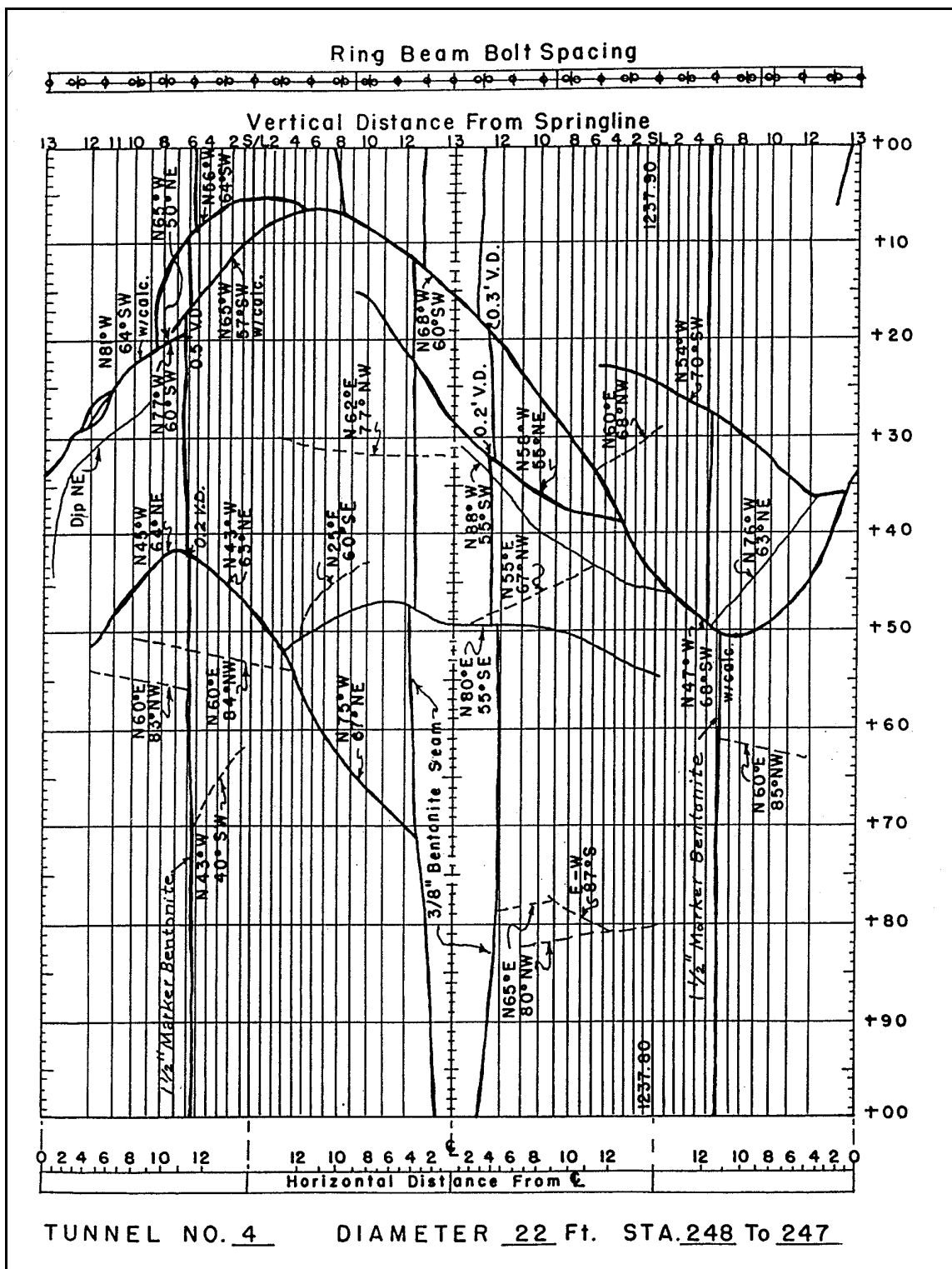


Figure C-1. Preparation of developed plan from a cylindrical cross section



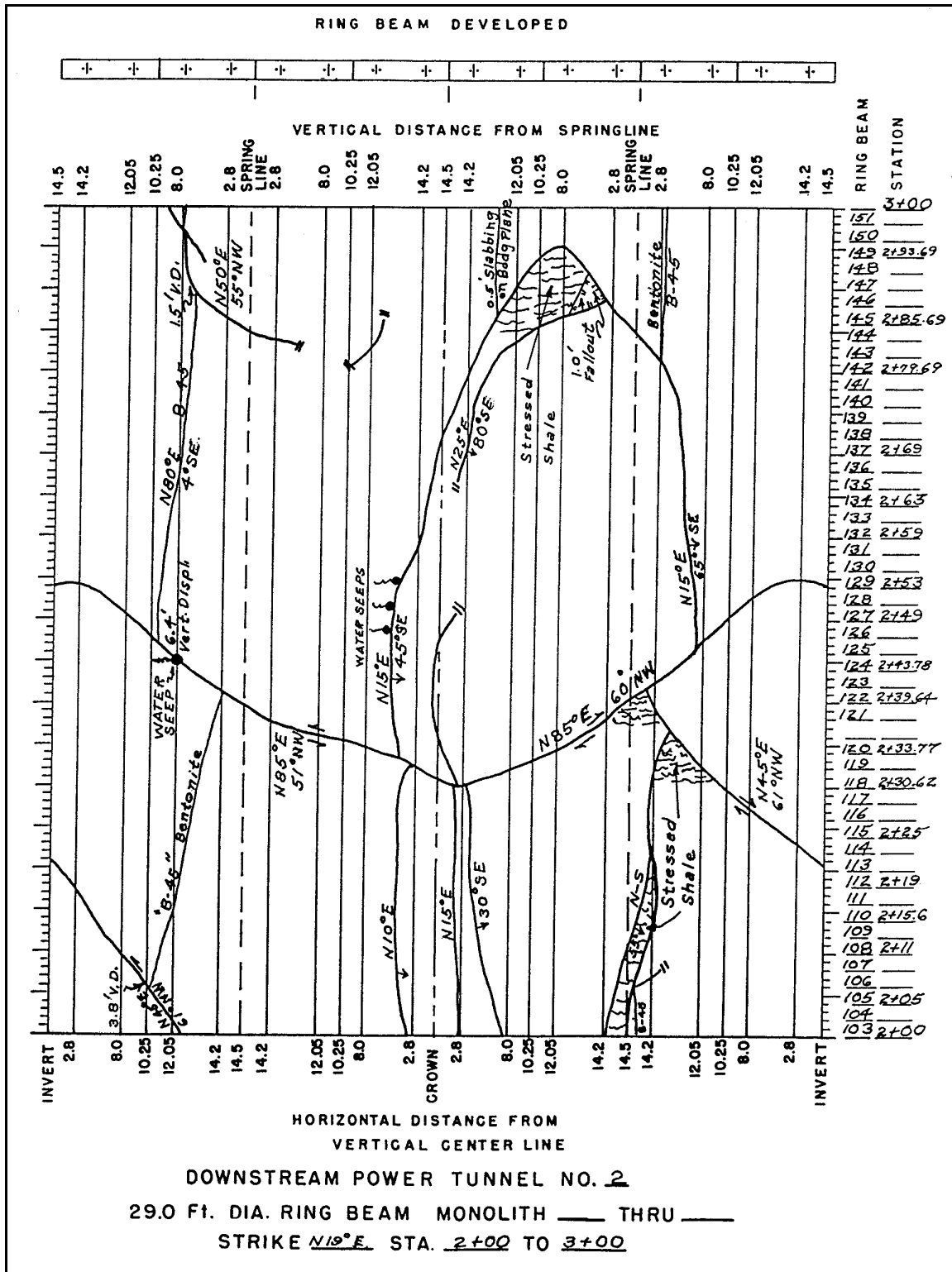


Figure C-3. Developed plan of cylindrical tunnel section Oahe Dam, South Dakota (note: 1 ft = approx. 0.3 m)

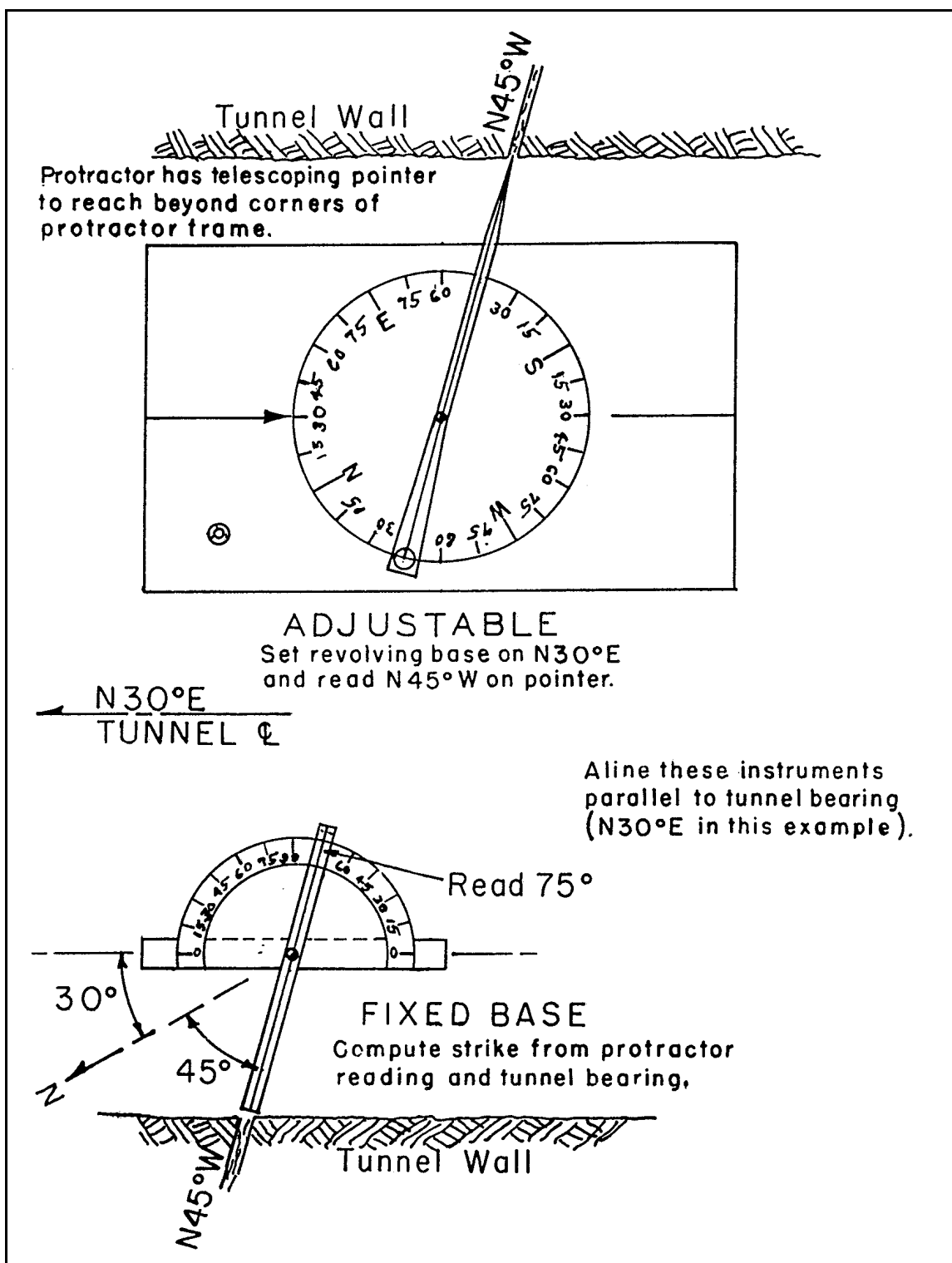


Figure C-4. Sketch of typical protractors used in peripheral geologic mapping

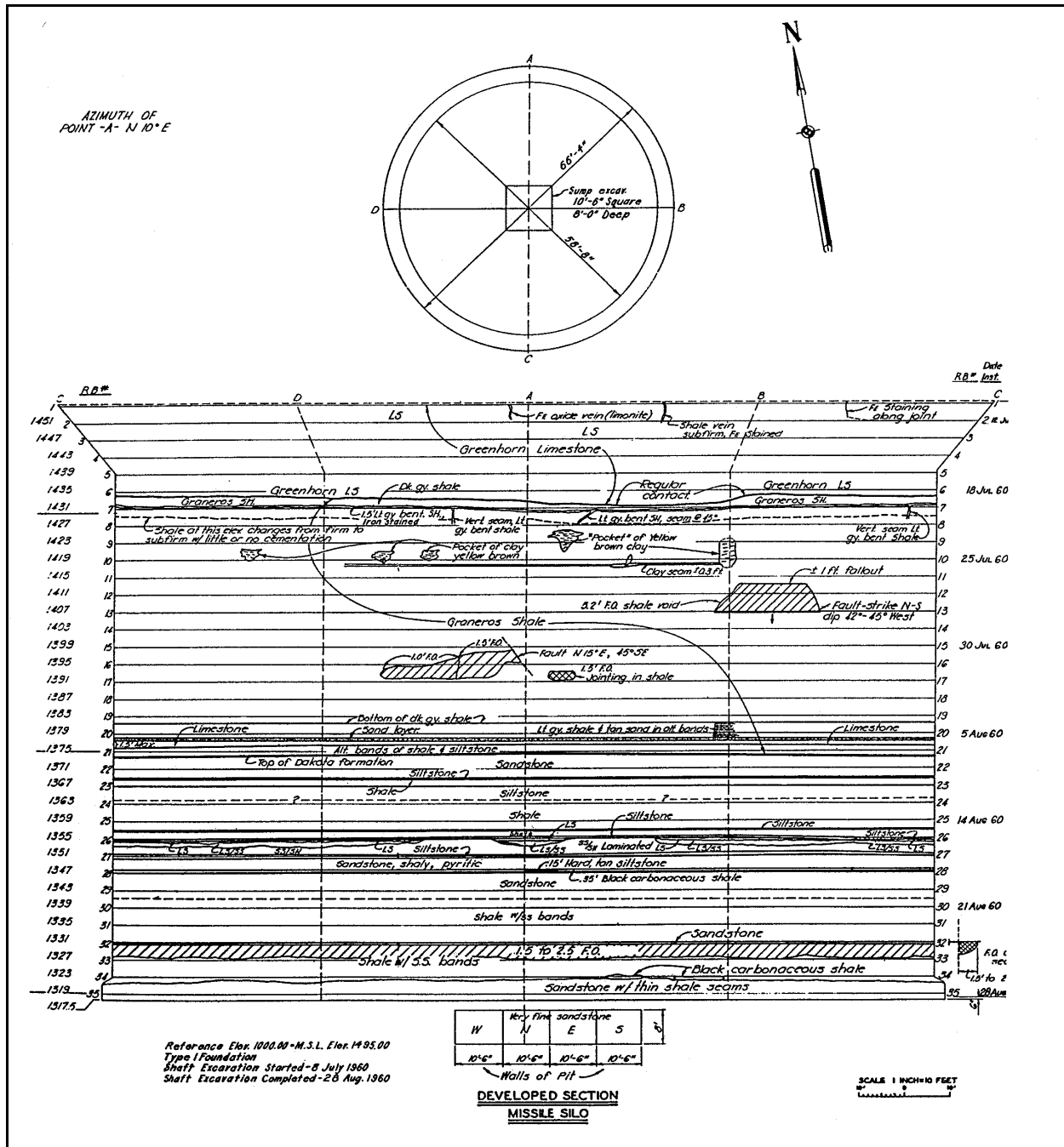


Figure C-5. Developed plan of a large-diameter, vertical, circular shaft (note: 1 ft = approx. 0.3 m)

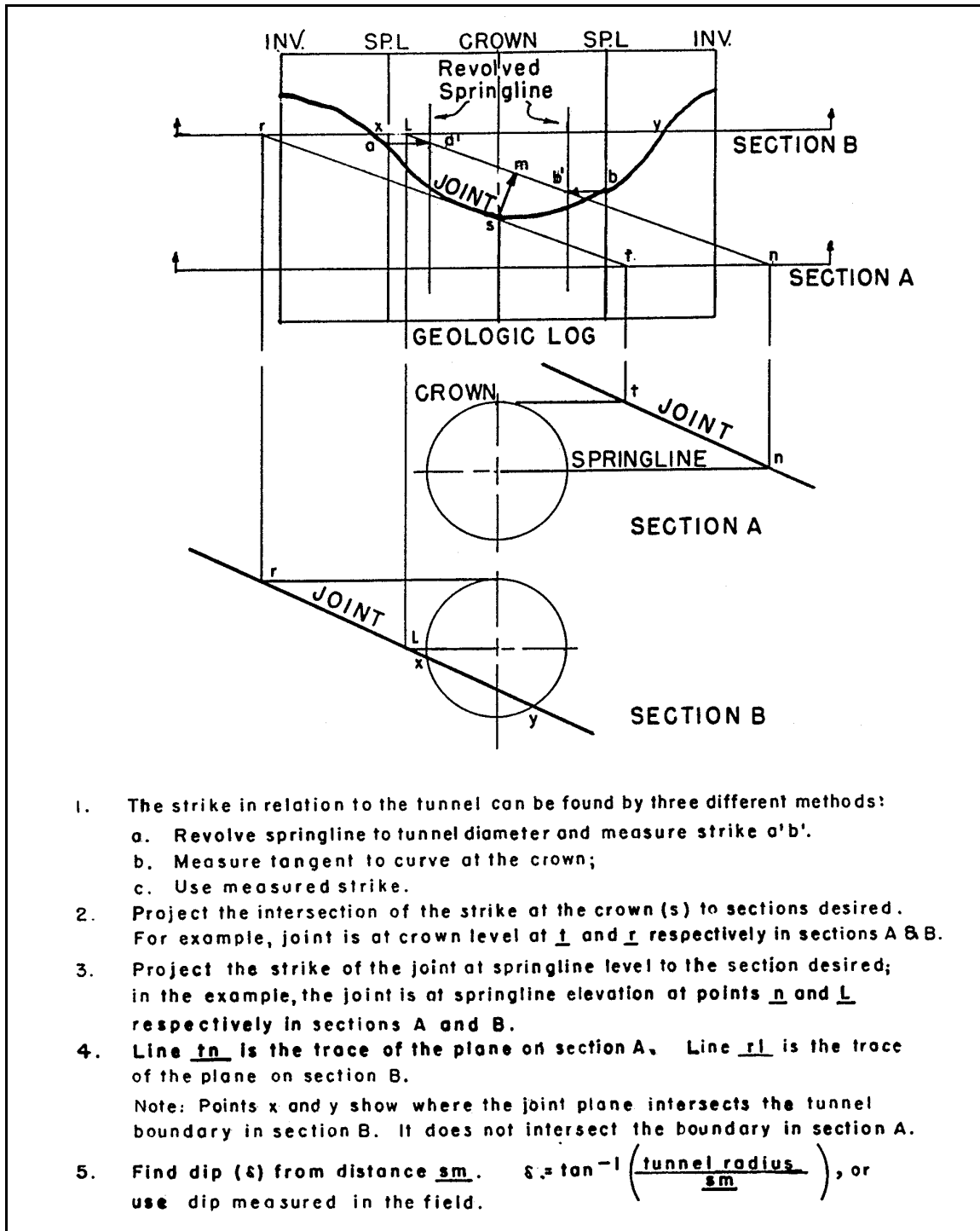


Figure C-6. Method of projecting geologic data to cross sections from geologic log as developed by R. E. Goodman, PhD, University of California

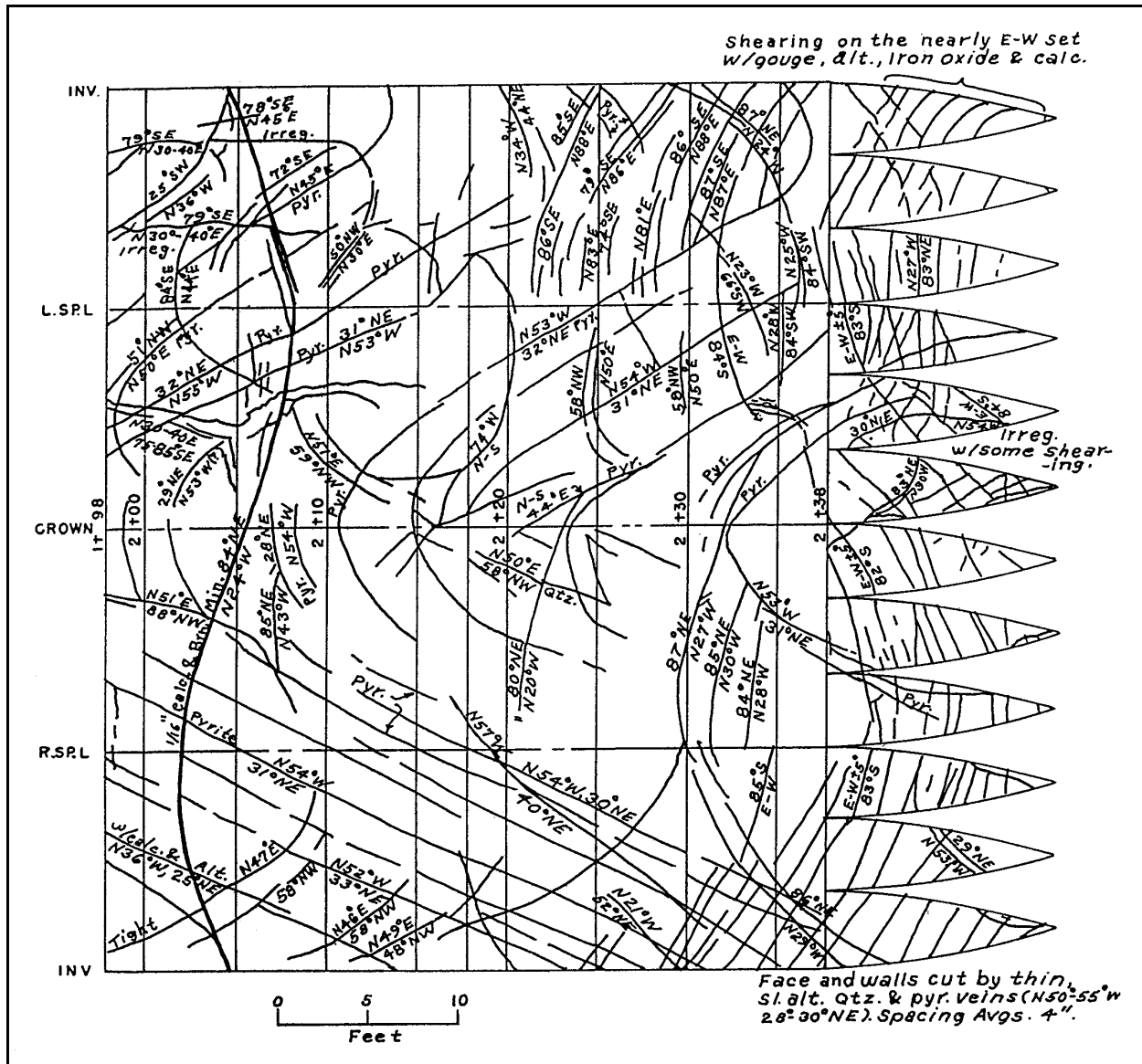


Figure C-7. Developed plan of a cylindrical drift with a hemispherical end section (in scale, 5 ft = approx. 1.5 m)

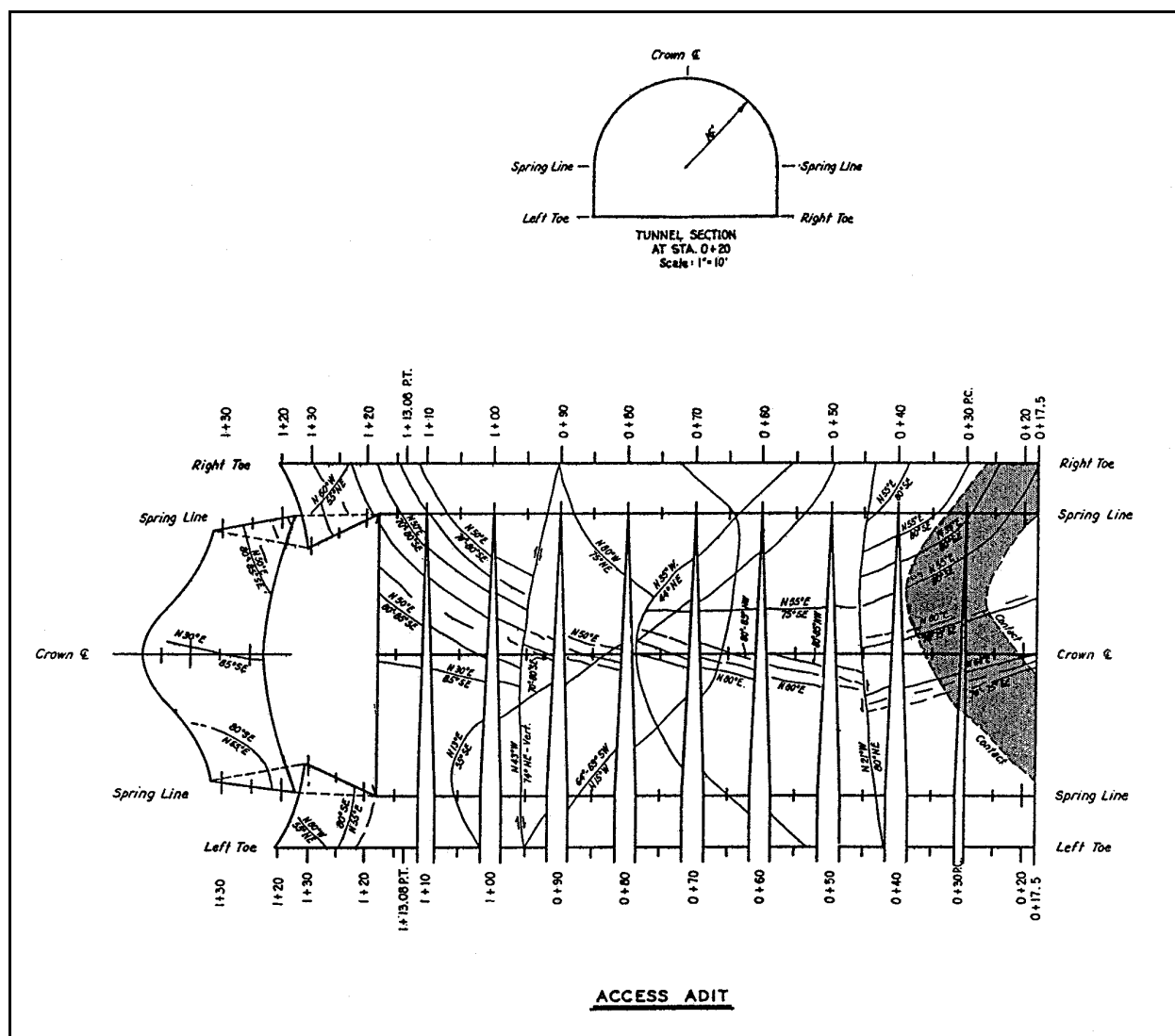


Figure C-8. Developed plan of a horseshoe-shaped drift with a curved center line and a transition to a larger drift

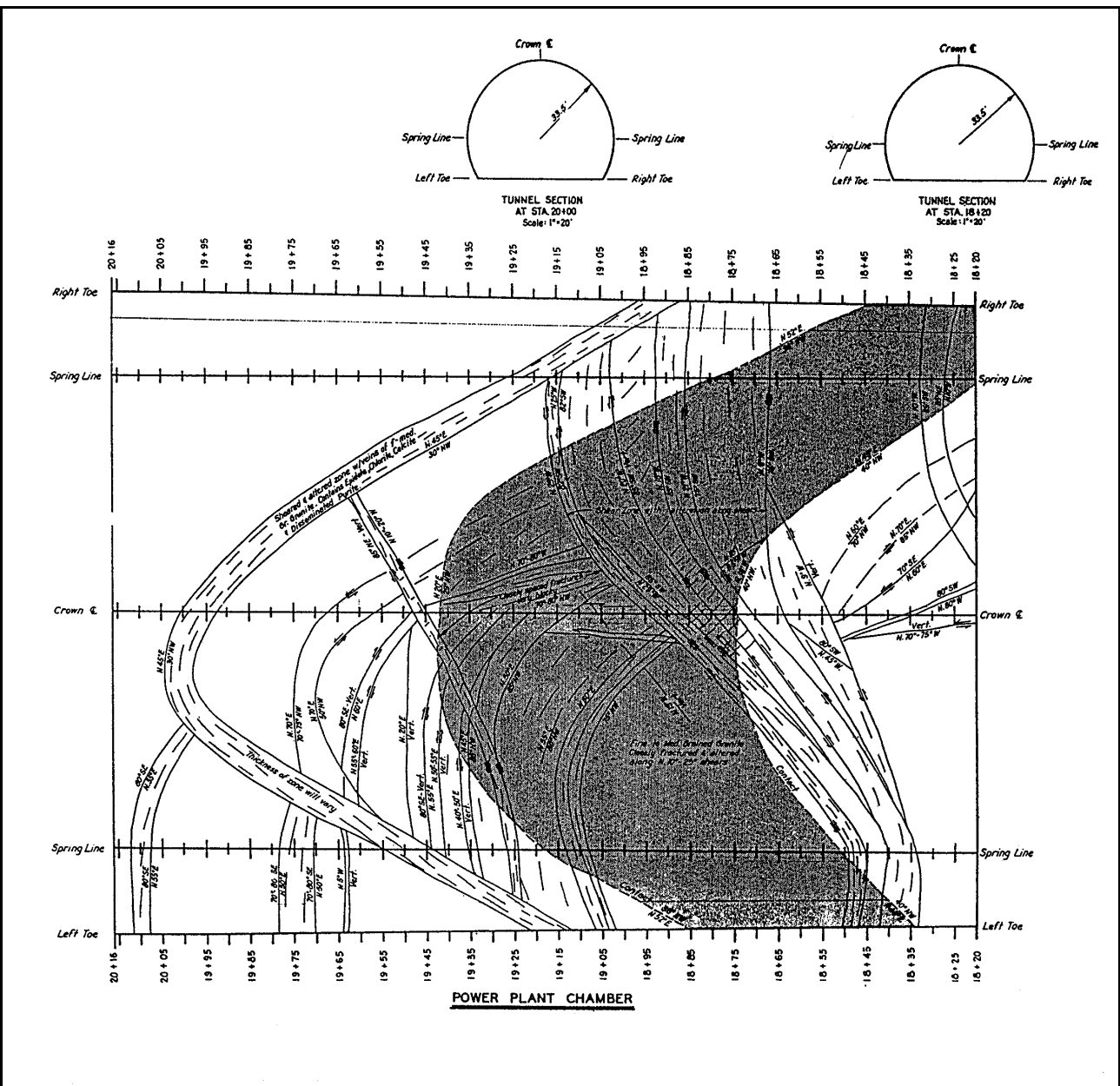


Figure C-9. Developed plan of a horseshoe-shaped large-diameter drift